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Tabu Search for Optimization of Military Supply Distribution

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Abstract

The dynamic and non-hierarchical nature of the military domain presents a challenge for traditional supply chain optimization. Flow networks and simulation techniques have been applied to the military distribution problem, but are unable to provide time-definite delivery to customers. Recently, optimization approaches have been independently applied towards strategic and operational levels of planning. However, decomposing military distribution into separate problems forces optimization techniques to utilize imprecise data. The size of the military distribution problem has prevented optimization techniques from providing end-to-end planning capabilities. This paper presents a Tabu Search algorithm for simultaneously solving strategic and operational levels of planning. The algorithm uses partial-order planning to separate the optimization process from the constraint verification process. The problem is reduced to a tractable computation by representing scenarios as two-tier systems and only permitting transshipments between different tiers. The results verify that the presented algorithm discovers higher quality solutions than simulation for simultaneously solving strategic and operational levels of planning.

Keywords: agents, logistics, military, operational planning, strategic planning, scheduling, simulation, supply chain optimization, Tabu Search

1. Introduction

Traditional supply chain techniques have been shown to produce inefficient plans when applied in the military domain. Serious shortcomings have illustrated the need for improved logistical processes in military operations such as Desert Storm (Kaminski, 1995) and Allied Force (Brooks, 2000). More recently, the shortfall of add-on-armor in Iraq confirmed supply chain problems (Bowman, 2003). It is necessary to discard the “just-in-case inventory” approach (Schrady, 1999) and move to a rapid and reliable transportation process that provides time-definite delivery to customers (Crino et al, 2002).

The military domain presents a challenge for supply chain optimization, because problems are dynamic and non-hierarchical. Problems in the military domain are more dynamic than problems in the commercial domain, because military problems operate in hostile environments. The military distribution problem may include several theaters of operation, which change as a plan is executed. Threats and unforeseen contingencies may cause a plan to become invalid. If hostile forces attack a convoy, then an alternate plan must be generated to distribute supplies to units. Therefore, the military requires a tool for efficiently responding to changes in a scenario.

The military distribution problem has been represented hierarchically by traditional planning techniques, such as flow networks and simulation. Modeling the problem hierarchically allows the problem to be decomposed into smaller problems, but fails to accurately represent the problem. The military distribution problem does not fit this structure for two reasons: the destinations of supplies are unknown before planning; and, supplies may be delivered from multiple theaters of operation. Therefore, it is necessary to discard the hierarchical approach and utilize an ad-hoc structure.

Military supply distribution is divided into strategic, operational and tactical levels of planning. Operational planning consists of the allocation of supplies and personnel between different locations within a theater. A theater is defined as a geographical area of operation outside of the continental United States under the responsibility of a commander (Crino et al, 2002). Strategic planning consists of the distribution of supplies, personnel, and transportation assets between different theaters of operation. The tactical level of planning specifies the movement of supplies from locations within a theater to individual units. This paper considers only the strategic and operational levels of planning.

The military distribution problem consists of the end-to-end distribution of supplies and personnel between geographical areas of operation. The objectives are to minimize shortfall and minimize the cost required to execute plans. A planning system must meet the following requirements: end-to-end planning; routing and scheduling of transportation assets at the strategic and operational levels; and, time-definite deliveries.

2. Related Work

Current planning techniques include planning by hand, flow networks, simulation, and optimization. Planning by hand is feasible for small scenarios. However, solutions generated by Tabu Search are significantly superior to those obtained by hand for large problem sets (Semet and Taillard, 1993). Planning by hand is unsuitable for the military distribution problem, because scenarios are subject to frequent change.

Problems in the commercial domain are often represented hierarchically and analyzed using supply chain techniques to trace the throughput of each node (Beamon, 1998). Supply chain techniques allow planners to identify problems in the distribution system and react accordingly. Flow networks are a supply chain technique that has been applied to the military domain (McKinzie and Barnes, 2004), providing a tool for analyzing the throughput of hubs in a scenario. Supply chain techniques maximize the throughput of individual nodes, but are unable to provide time-definite deliveries to customers.

Simulations are ruled-based models for solving the military distribution problem (Wu et al, 2003). Simulation models attempt to model military scenarios as accurately as possible. Therefore, plans generated by a simulation are valid for real-world scenarios. Rule-based models are an effective technique for satisfying constraints, but fail to optimize the utilization of resources. Simulations provide a tool for efficiently generating feasible plans. However, simulation models applied to end-to-end planning have been unable to prescribe routing and scheduling of transportation assets at the operational level (Crino et al, 2002).

Current research has utilized optimization techniques for solving the military distribution problem. Most attention has focused on the use of Tabu Search to optimize the utilization of resources. Optimization techniques using Tabu Search have demonstrated the ability to schedule transportation assets at the operational level and provide time-definite deliveries to customers. Tabu Search has been applied towards planning at the strategic level (Barnes et al, 2004) and planning at the operational level (Crino et al, 2002). However, the size of the military distribution problem has prevented optimization techniques from providing end-to-end planning capabilities.

3. Tabu Search Approach

This paper presents a Tabu Search algorithm for simultaneously solving strategic and operational levels of planning. Tabu Search combines greedy heuristics and memory structures to effectively traverse through solution spaces (Glover and Laguna, 1997). The algorithm uses partial-order planning to separate the optimization process from the constraint verification process. The problem is reduced to a tractable size by representing problems as two-tier systems. Also, the search incorporates additional heuristics to improve performance. The result is an algorithm that quickly converges to feasible solutions.

The algorithm uses partial-order planning to achieve a combination of simulation and optimization, and utilizes an approximated objective function that separates the intelligent component of the algorithm from the constraint-checking component. The intelligence of the algorithm is represented as an objective function, used by the search. However, it may be impractical to consider all necessary constraints through an objective function. Therefore, the search considers only those constraints that directly affect the quality of a solution. The algorithm uses an objective function to determine which deliveries to consider for addition to the current plan. Once a candidate delivery has been selected, the constraint portion of the algorithm determines when the delivery should be scheduled and verifies the delivery against a set of rules.

This hybrid approach offers two benefits, but there is a tradeoff. The first benefit is faster iterations compared to a pure optimization approach, since constraint verification is applied to a single delivery each iteration. The second benefit is that the planning agent can handle additional constraints without modification of the optimization portion of the algorithm. However, the optimization component may select a move that violates constraints, because the objective function does not consider all constraints. Therefore, the optimization component may select a poor quality move that degrades the quality of the solution. This problem is resolved using feedback from resulting solutions. The search is informed if a selected delivery improves or degrades the quality of a solution.

The algorithm represents scenarios as two-tier systems. Deliveries at the strategic level represent the top tier, while deliveries at the operational level represent the bottom tier. The search alternates between two modes. In the first mode, the search schedules deliveries for the bottom tier and ignores transshipments. In the second mode, the planning agent schedules deliveries for the top tier and allows transshipments between the different tiers. The planning agent limits deliveries to a maximum of two transshipments and only a single top-tier delivery is permitted.

This structure prevents the algorithm from solving all possible scenarios, but greatly reduces the permutations of deliveries considered by the algorithm.

The Tabu Search algorithm uses the following heuristics to improve the performance of the search: scheduling heuristic; pick-up heuristic; and, removal heuristic. The scheduling heuristic determines when to schedule deliveries by trying to schedule all deliveries as early as possible. However, if a conveyance does not have an opening for an additional delivery, then the scheduling heuristic ejects deliveries that deliver to customers with later request times until an opening is available. The pick-up heuristic is used to estimate the cost to transport supplies from within a theater to locations used for transshipments. It enables the algorithm to consider transportation assets at the operational level when planning deliveries at the strategic level. The last heuristic is the removal heuristic, which deterministically removes deliveries from the solution. The heuristic verifies that customers are supplied from the closest possible supply location. If a customer is not satisfied from the closest supply location, then deliveries currently using the location are ejected from the solution.

4. Results

The performance of the Tabu Search algorithm was tested in six scenarios against a simulation model. The scenarios were designed to test various aspects of the Tabu Search algorithm and demonstrate the non-hierarchical nature of the military supply distribution problem. The ‘Greedy’ and ‘Theater’ scenarios demonstrate the strengths of the heuristics. The ‘Non-hierarchical’ and ‘Multi-theater’ scenarios demonstrate the ability of the Tabu Search algorithm to solve multi-theater problems. Finally, the ‘Cargo’ and ‘World’ scenarios validate the ability of the Tabu Search algorithm to solve large problems. A summary of results for the testing scenarios is listed in Table 1. Shortfall represents unmet customer demand. Tabu Search was able to satisfy more customer demand than the simulation for all of the scenarios tested. Also, Tabu Search converged to solutions in less than two minutes for the largest scenarios. Even though the travel distances required for the Tabu Search solutions are consistently longer than the distances for the simulation solutions, it should be noted that the differential reduces to less than 7% with increasing complexity and size of the problem space. Furthermore, the Tabu Search algorithm was able to accomplish all deliveries, except for the World scenario, while the simulation solutions resulted in significant shortfalls. The results verify the feasibility of optimization techniques for strategic and operational levels of planning and demonstrate that Tabu Search outperforms current simulation techniques.

	Simulation Shortfall	Simulation Distance	Tabu Search Shortfall	Tabu Search Distance
Greedy	1	100	0	600
Theater	20	6055	0	7407
Non-hierarchical	42	23206	0	32127
Multi-theater	16	40254	0	41745
Cargo	656	2422633	0	2525579
World	508	4564128	17	4859124

Table 1 - Scenario results

5. Conclusion

Current supply chain techniques are unable to meet the requirements for the military distribution problem. Optimization techniques attempt to find optimal solutions and therefore cannot solve large-scale scenarios. This paper presents a Tabu Search algorithm that sacrifices optimality for practical run-time computation by separating the optimization component from the constraint-checking component and limiting the combinations of feasible transshipments. The Tabu Search algorithm combines the strengths of simulation and optimization through the use of partial-order planning. The performance of the Tabu Search algorithm was tested in six scenarios against a simulation model. Tabu Search discovered superior solutions on all problem sets and all solutions were found in less than two minutes. The results verify the ability of Tabu Search to solve at the strategic and operational levels of planning.

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